NACA

RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION AT LOW TRANSONIC SPEEDS

OF THE EFFECTS OF NUMBER OF WINGS ON THE

LATERAL-CONTROL EFFECTIVENESS OF AN RM-5 TEST VEHICLE

By Harold S. Johnson

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

CLASSIFICATION CANCELLED

Authority naca R72457 Date 8/18/54

4 9/1/54 See

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
November 29, 1949

UNCLASSIFIED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION AT LOW TRANSONIC SPEEDS

OF THE EFFECTS OF NUMBER OF WINGS ON THE

LATERAL-CONTROL EFFECTIVENESS OF AN RM-5 TEST VEHICLE

By Harold S. Johnson

SUMMARY

An investigation was performed to determine the effects
of number of wings on the aileron rolling effectiveness of
an RM-5 test vehicle using the free-rolling wind-tunnel testing
technique through a speed range to a Mach number of 0.9. Since
free-flight models must have three or more wings for stability,
the investigation was conducted to determine the validity of
applying multiwing test results to conventional airplane configura-
tions. The test-vehicle wings had neither taper nor sweepback
and were equipped with full-span 20-percent-chord sealed and faired
ailerons.

The results of this investigation showed that increasing the
number of wings resulted in a decrease in rolling effectiveness
so that the results obtained from the test of the three-wing
model were closer to conventional-airplane-configuration results
than were the four-wing data. The effects of compressibility
occurred at progressively lower Mach numbers as the number of wings
was increased from two to four.

INTRODUCTION

During the last several years, investigations have been undertaken
to solve the problems of obtaining adequate lateral control at
transonic and supersonic speeds. The experimental data have been
obtained through the use of different testing methods, each of which
has its limitations with regards to such factors as Reynolds number,
Mach number range, and type and size of model. One testing technique
consists of firing free-flight rocket-propelled test vehicles having

preset deflected ailerons. From transmitted records of the flight,
the variations of wing—tip helix angle and drag coefficient with
Mach number are obtained. For free—flight stability the RM—5 test
vehicles must have three or more wings.

This paper presents the results of a wind—tunnel inves-
tigation of RM—5 test vehicles, with two, three, and four wings,
conducted to determine the validity of applying multiwing test
results to conventional airplane configurations. The RM—5 test
vehicles were mounted on a free—roll sting support in the Langley
high—speed 7— by 10—foot tunnel and were tested through a speed
range to a Mach number of about 0.9.

COEFFICIENTS AND SYMBOLS

$\dfrac{pb}{2V}$ wing—tip helix angle, radians

C_D drag coefficient (D/qS)

ΔC_D increment of drag coefficient (C_D, complete
configuration — C_D, body)

C_l rolling—moment coefficient of the model with deflected
ailerons (L/qSb)

C_{l_p} damping—in—roll coefficient $\left(-\dfrac{C_l}{pb/2V}\right)$

L rolling moment, foot—pounds

D drag, pounds

p rolling velocity, radian per second

b diameter of circle swept by wing tips (with regard to
rolling characteristics, this is considered to be
the effective wing span of the test vehicles), feet

V free—stream velocity, feet per second

q dynamic pressure, pounds per square foot $\left(\dfrac{1}{2}\rho V^2\right)$

ρ mass density of air, slugs per cubic foot

S   total wing area, (wings assumed to extend to
           model center line) square feet

M   Mach number (V/a)

a   speed of sound, feet per second

δ   twice average aileron deflection measured in plane
           perpendicular to chord plane and parallel to
           center line (equivalent to the total deflection
           of the oppositely deflected ailerons on a conven-
           tional wing configuration), degrees

i_w average wing incidence, radians

CORRECTIONS

All tunnel values of coefficients and Mach number have been
corrected for blocking caused by the model and its wake. The blockage
corrections were computed by the methods presented in reference 1.
The coefficients have not been corrected for the effects of tares.
Tests of other sting-supported models in the tunnel have shown the
tare corrections to rolling-moment coefficients to be negligible.
The rolling velocities have, however, been corrected for the small
bearing-friction losses. Free-flight tests of wings of the same
order of torsional rigidity as those of the present investigation
have indicated that corrections of the rolling effectiveness
parameters for the loss of aileron effectiveness due to wing twisting
can be neglected (reference 2).

The average wing incidence of the models varied from −0.1°
to 0.3°. The tunnel values of $\frac{pb}{2V}$ have been approximately corrected
to 0° of wing incidence by applying the following increment:

$$\Delta\frac{pb}{2V} = \frac{3}{2}i_w$$

The constant in the equation is the ratio of the centers of pressure
for air load due to rolling and angle of attack, based on airfoil
strip theory.

The rolling—moment coefficients were corrected to 0° of wing incidence by the relationship:

$$-\frac{c_{l_u}}{(pb/2V)_u} = c_{l_p} = -\frac{c_l}{pb/2V}$$

where the subscript u indicates that the values are uncorrected for the effects of incidence.

MODELS AND TESTING TECHNIQUES

The general arrangement of the RM—5 test vehicles used in the investigation is shown in figure 1. The models consisted of a pointed cylindrical wood body at the rear of which were attached wings having preset fixed—aileron—type controls. The wings were constructed of laminated spruce with steel stiffeners cyclewelded into the upper and lower wing surfaces. The wings were rectangular in plan form and were unswept. The aspect ratio, based on the area of two wings, was 3.7, and the airfoil section was NACA 16—009. The full—span, 20—percent—chord ailerons, which were formed by deflecting the section chord line at the 0.8—chord line, simulate sealed, faired, plain ailerons in actual airplane construction. The dimensional characteristics of the test vehicles used in the present investigation are given in table I and figure 1. The wing configuration was known to have a rapid reversal of control effectiveness at high subsonic Mach numbers. Models with two, three, and four wings were tested.

The rocket motor was replaced by a steel shaft which extended behind the test vehicle and was mounted within a free—roll sting support located downstream from the test section. (See fig. 2.) A more complete description of the free—roll testing equipment is given in reference 3. Rolling moments and drag were measured with the models restrained in roll, and the rolling velocities were electrically recorded with the models free to roll. From these measured data, rolling—moment and drag coefficients, wing—tip helix angles, and damping—in—roll coefficients were obtained for the Mach number range from 0.5 to 0.9.

The size of the models used in the investigation resulted in an estimated choking Mach number of 0.94, and the tunnel data are believed to be reliable to a corrected Mach number of about 0.91.

The variation of Reynolds number with Mach number for average
test conditions is presented in figure 3. The Reynolds numbers are
based on the average wing chord of 0.59 foot.

RESULTS AND DISCUSSION

Wing—Aileron Rolling Effectiveness

The variations of wing—tip helix angle per twice the average
aileron deflection $\frac{pb/2V}{\delta}$ with Mach number are presented in figure 4
for the two—, three—, and four—wing test vehicles. The helix
angles are expressed as a function of twice the average aileron
deflection to represent the helix angle resulting from a 1° total
aileron deflection (the summation of the oppositely deflected
ailerons) on a conventional two—wing configuration. The test
points are presented for the three—wing arrangement to show the
scatter of test points. The scatter for the other models was about
the same and, for clarity, the test points are not presented. The
three models showed a large and rapid loss of rolling effectiveness
at high transonic Mach numbers. This loss of rolling effectiveness
occurred at progressively lower Mach numbers as the number of
wings was increased. The two—wing model did not exhibit a
reversal of effectiveness for the speed range tested. The three—
wing data showed that a reversal was indicated at a Mach number
slightly above the highest Mach number attained (M = 0.91). The
test results showed that the four—wing model exhibited a
reversal of aileron effectiveness at a Mach number of about 0.88.

Throughout the Mach number range investigated the values of $\frac{pb/2V}{\delta}$
decreased as the number of wings was increased. For Mach numbers
less than about 0.8, the greatest loss in rolling effectiveness
is noted when the two— and three—wing results are compared. The
addition of a fourth wing gave results only slightly lower than
the three—wing values.

These results indicate that the use of three or four wings
on test vehicles, a necessity to provide free—flight stability,
appears to give pessimistic values of rolling effectiveness and
lower values of Mach number at which compressibility effects are
noted. The data also show that it is desirable to use a three—wing
model in free flight in preference to a four—wing vehicle if
the data are to be applied to conventional airplane configurations,
especially for configurations that exhibit marked compressibility
effects.

Rolling-Moment Coefficients

The effects of Mach number and number of wings on the rolling-moment coefficients (based on total wing area) are generally similar to those exhibited by the rolling-effectiveness curves, although the decrease in rolling-moment coefficient varied more nearly linearly with increasing number of wings for the Mach number range covered in the investigation (fig. 5). The rolling-moment coefficients decreased slightly with increasing Mach number below $M \approx 0.85$, and then decreased rapidly with further increases in Mach number. The rapid loss in C_l occurred at progressively lower Mach numbers as the number of wings was increased. Rolling-moment reversals occurred at Mach numbers of about 0.91 and 0.88 for the three- and four-wing models, respectively. The two-wing model did not exhibit a reversal in the test range.

Damping-in-Roll Coefficients

The variation of the damping-in-roll coefficients with Mach number is presented in figure 6. For the three models tested, the data indicate the C_{l_p} decreased slightly with increasing Mach number up to a Mach number of about 0.75, and then generally increased with further increases in Mach number. Values of C_{l_p} for Mach numbers greater than 0.85 are not presented because the determination of C_{l_p} at the higher Mach numbers becomes very inaccurate because of the rapid variations of rolling moment and rolling effectiveness with Mach number. The agreement between the results of the two- and three-wing models is good, but the C_{l_p} values of the four-wing model were only about 80 percent of those of the two-wing or three-wing arrangements.

Drag Measurements

Since drag tares could not readily be determined, the drag of a test vehicle without wings was measured for the Mach number range and increments of drag coefficient (drag coefficient of model less drag coefficient of body) were computed. These increments are presented in figure 7. The effects of increasing the number of wings on ΔC_D were generally the same as were exhibited by the rolling-effectiveness curves. The drag-coefficient increments of the three-wing model are considerably larger than that of

the two-wing model. The addition of the fourth wing resulted
in only a slight further increase in the drag increments for Mach
numbers less than about 0.8. The drag data exhibit large increases
at the higher subsonic Mach numbers and the breaks in the curves
occurred at progressively lower Mach numbers as the number of wings
was increased.

CONCLUDING REMARKS

The results of a wind-tunnel investigation of several RM-5
test vehicles performed to determine the effects of number of wings
on the aileron rolling effectiveness showed that increasing
the number of wings resulted in a decrease in rolling effective-
ness. The effects of compressibility occurred at progressively
lower Mach numbers as the number of wings was increased from
two to four. Since three or more wings must be used for free-
flight stability, the results indicate that a three-wing test
vehicle should be used in free flight in preference to a four-wing
model if the test results are to be applied to conventional airplane
configurations.

Langley Aeronautical Laboratory
    National Advisory Committee for Aeronautics
        Langley Air Force Base, Va.

REFERENCES

1. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow
     Closed-Throat Wind Tunnels, with Consideration of the Effect
     of Compressibility. NACA RM A7B28, 1947.

2. Sandahl, Carl A.: Free-Flight Investigation of Control Effectiveness
     of Full-Span, 0.2-Chord Plain Ailerons at High Subsonic,
     Transonic, and Supersonic Speeds to Determine Some Effects of
     Wing Sweepback, Taper, Aspect Ratio, and Section Thickness
     Ratio. NACA RM L7F30, 1947.

3. Myers, Boyd C., II, and Kuhn, Richard E.: High-Subsonic Damping-
     in-Roll Characteristics of a Wing with the Quarter-Chord Line
     Swept Back 35° and with Aspect Ratio 3 and Taper Ratio 0.6.
   NACA RM L9C23, 1949.

CONFIDENTIAL

TABLE I

DIMENSIONAL CHARACTERISTICS

Airfoil section	NACA 16–009
Span, in.	26.21
Area (one wing), sq in.	[a]92.72
Aspect ratio	[b]3.7
Taper ratio	1
Sweptback, quarter chord, deg	0
Aileron span	Full
Aileron chord, percent wing chord	20
Average aileron deflection, deg:	
Two–wing model	3.60
Three–wing model	4.00
Four–wing model	4.16

[a]Wing assumed to extend to model center line.
[b]Based on area of two wings.
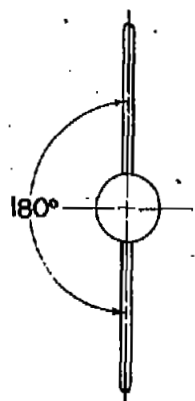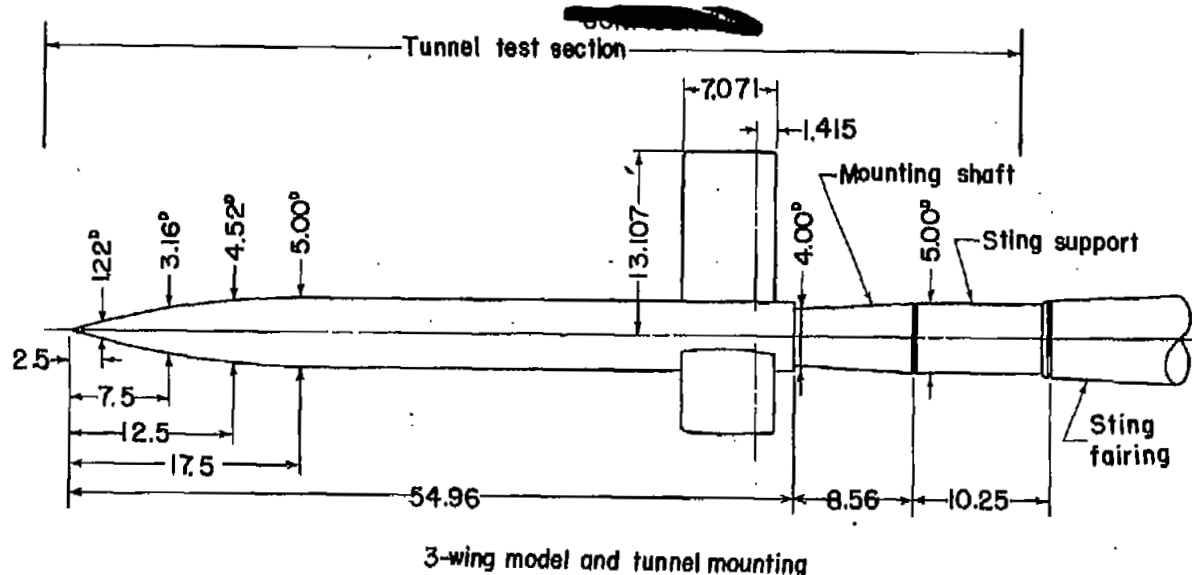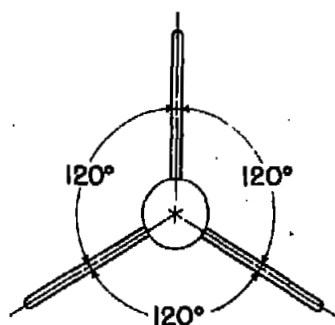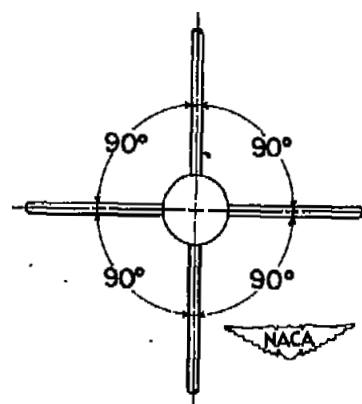
Figure 1.— Drawing of the RM-5 test vehicles used for the investigation. (All dimensions are in inches.)
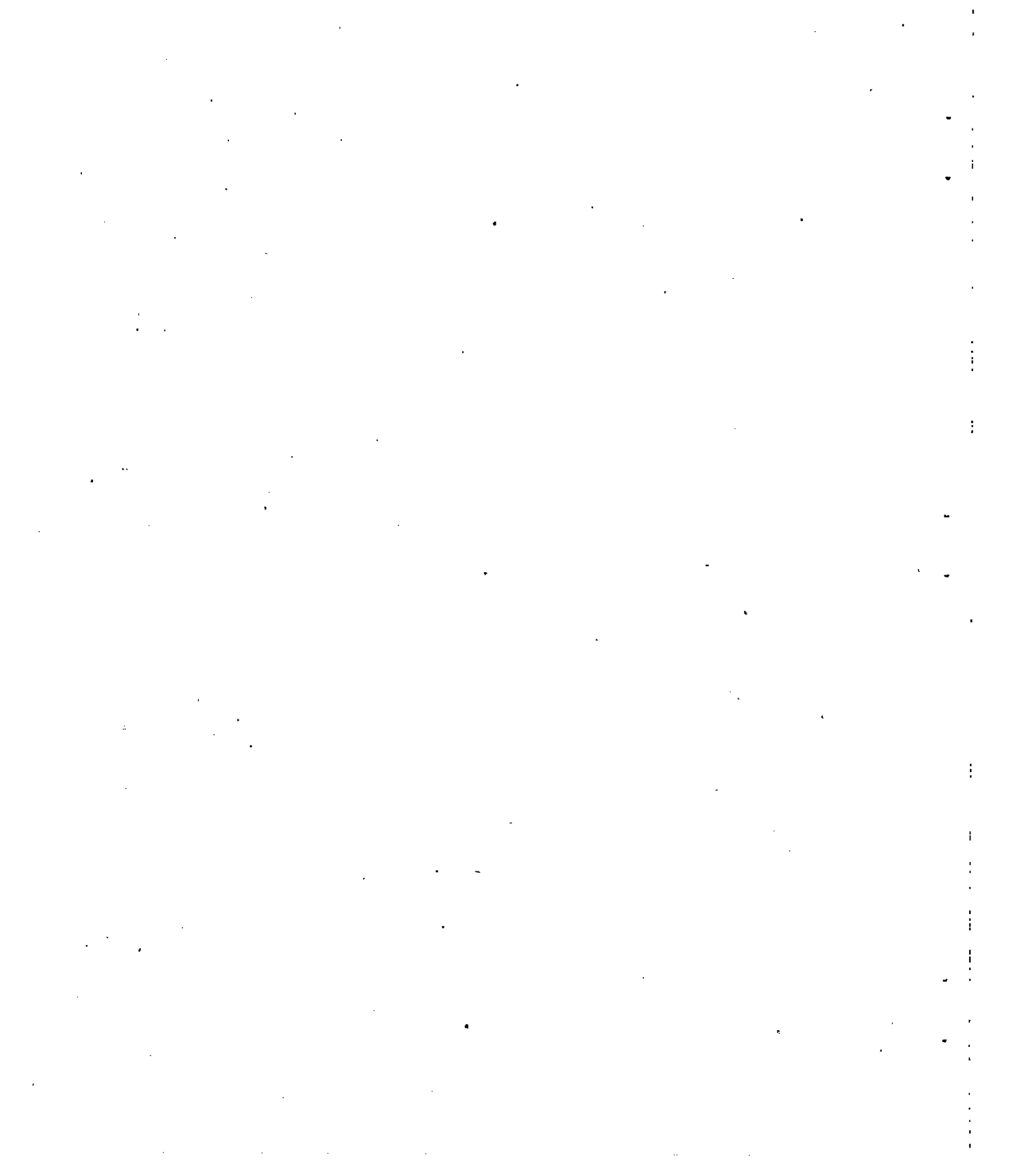
Figure 2.— Photograph of an RM–5 test vehicle mounted on the free–roll sting support in the Langley high–speed 7– by 10–foot tunnel.
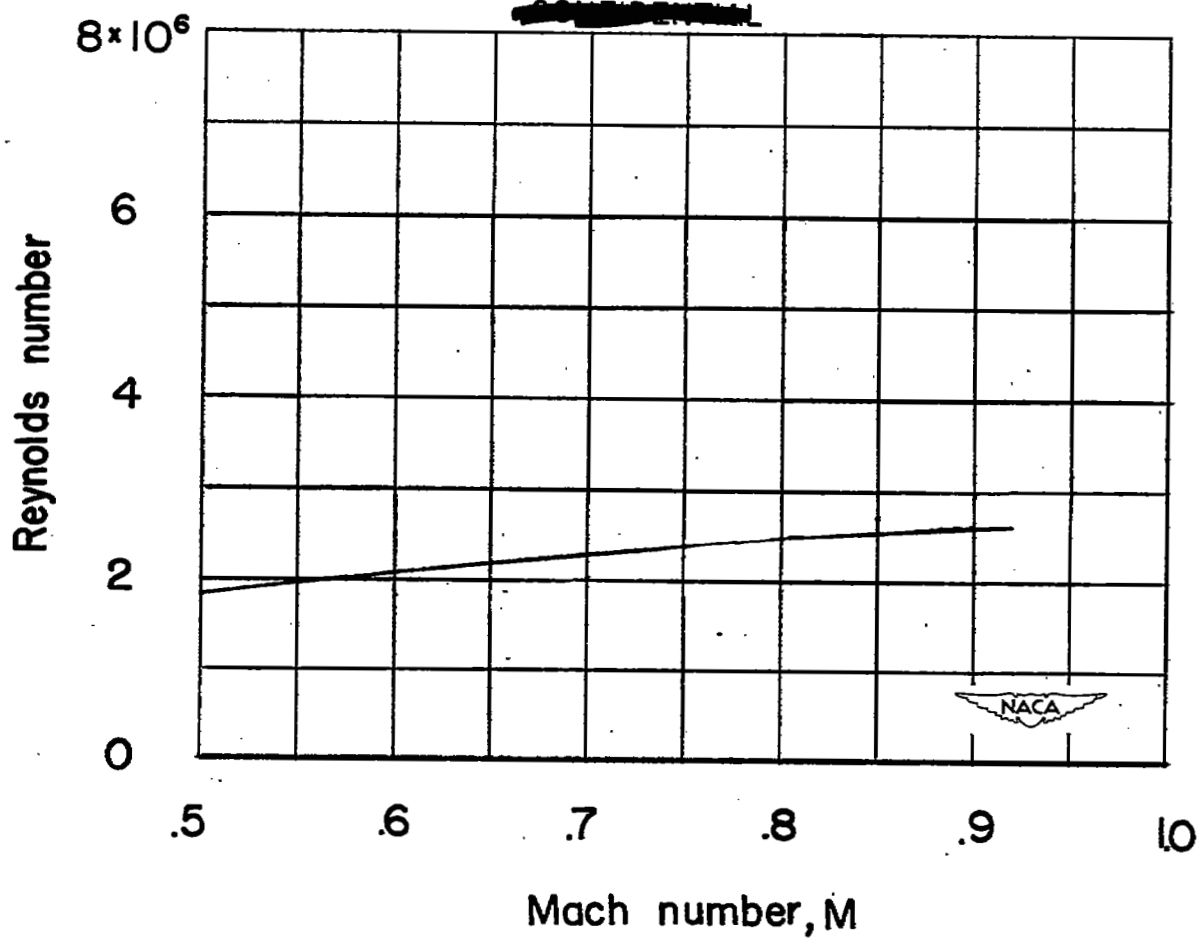
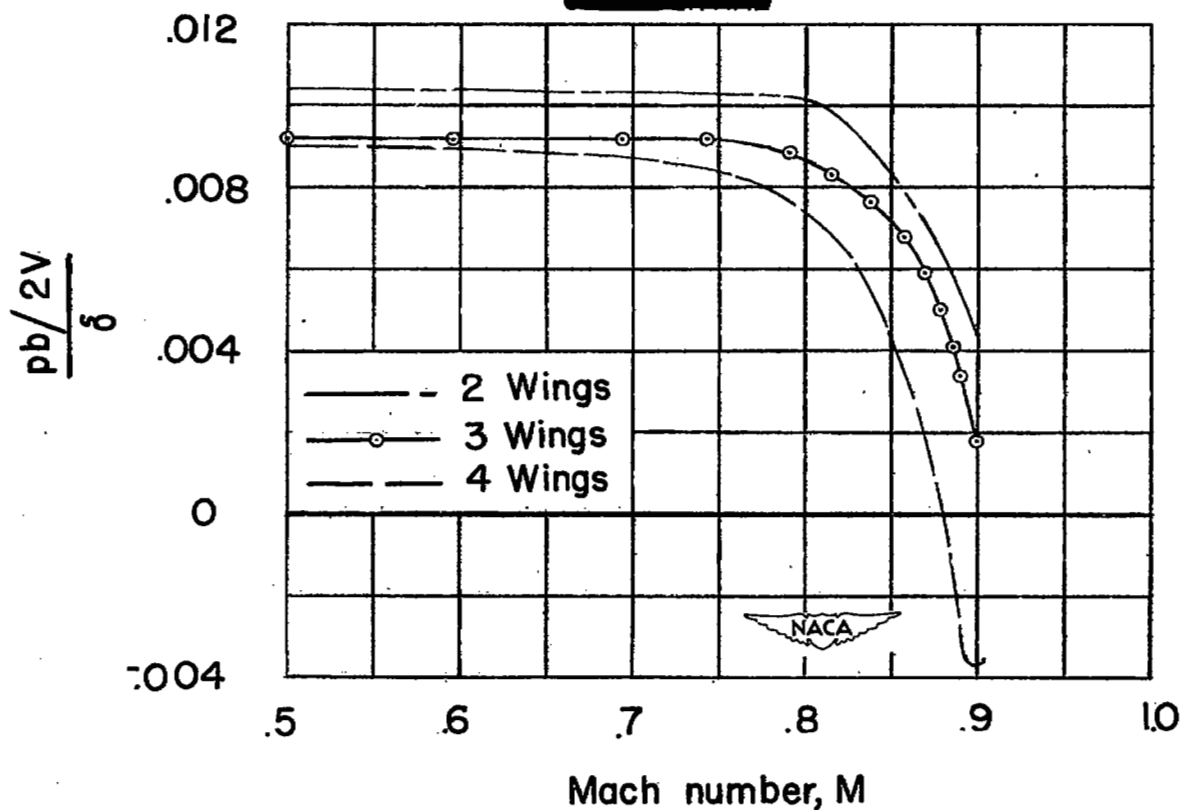Figure 3.— Variation of average Reynolds number with Mach number.

Figure 4.— Effect of number of wings on the variation of rolling effectiveness with Mach number.
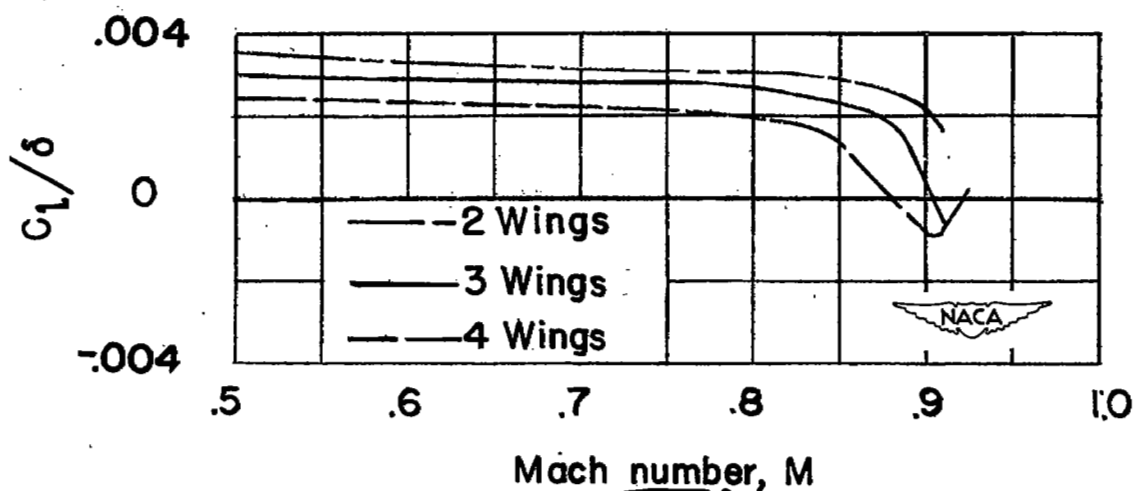

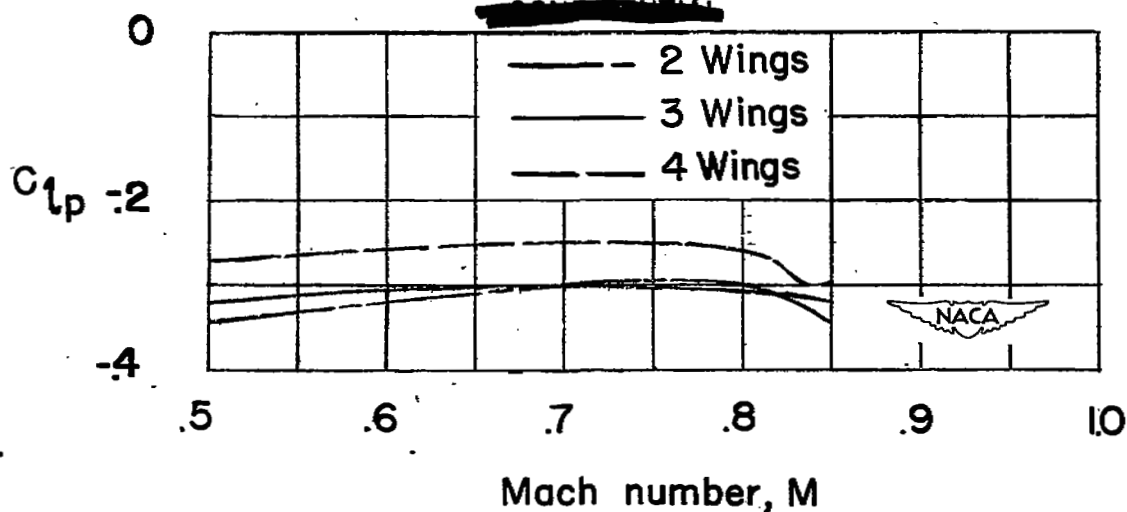Figure 5.— Variation of rolling-moment coefficient with Mach number.

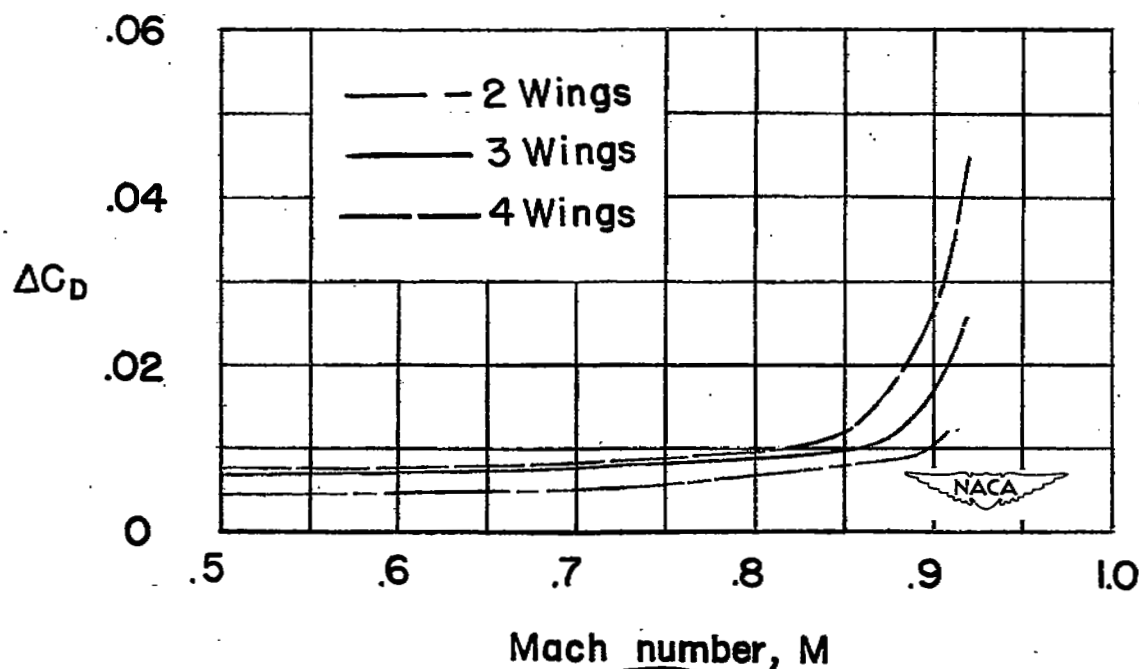Figure 6.— Variation of the damping—in—roll coefficient with Mach number.

Figure 7.— Effect of number of wings on the variation of drag
coefficient with Mach number.